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**TEST RESULTS OF RESEARCH FOR
RAPID SITE PREPARATION FOR VTOL AIRCRAFT**

A. VASILOFF

TECHNICAL DOCUMENTARY REPORT No. APL-TDR-64-104

NOVEMBER 1964

AIR FORCE AERO PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 8174, Task No. 817401

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FOREWORD

This report presents the results of a test program conducted by the Air Force Aero Propulsion Laboratory in the development of landing sites for VTOL aircraft. Work was conducted under Project No. 8174, Task No. 817401, "Rapid Site Preparation for VSTOL/STOL Aircraft." Mr. A. Vasiloff was the project engineer for this program. Work covered in this report was accomplished from August 1962 to August 1964.

The author wishes to acknowledge the assistance of many persons who have contributed to this program. From the Air Force Aero Propulsion Laboratory, Messrs. W. Melvyn Roquemore, Associate Engineer, and Thomas Mahoney and Harvey Reeves, experimental aircraft engine operators, have aided in the experimental set-up and testing. From LTV, Vought Aeronautics Division, Dallas, Texas, (under Contract No. AF33(615)-1092), Messrs. J. E. Butler, G. F. Thomas, and H. J. Poskey aided in the formulation of the final resin material and assisted in the full-scale tests at Moffett Field, California. Mr. L. S. Rolls, the NASA X-14 project engineer, and Mr. Fred Drinkwater, the NASA pilot of the X-14 aircraft, aided in the conduct of the full-scale tests.

Motion pictures were taken of various phases of the test program and the film is available from the Air Force Aero Propulsion Laboratory.

Release of this report to the Office of Technical Services is not authorized because of patents pending on materials evaluated.

ABSTRACT

To operate VTOL aircraft in remote front-line areas, sites must be prepared to prevent flying foreign objects from damaging the aircraft. Research was conducted to determine whether any quick-setting soil hardeners could withstand the blast environment of the VTOL afterburner. Samples of numerous materials were tested in a special VTOL test facility consisting of a J-85-5 jet engine with afterburner that could be rotated to a vertical position to duplicate ground conditions imposed by the VTOL jet blast. A fast-curing, sprayable, resin formulation was developed and tested, and full-scale tests were made with an X-14 VTOL aircraft. This report reviews the results of these tests.

This technical documentary report has been reviewed and is approved.



ROSS J. CAFVERT
Chief, Support Techniques Branch
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INTRODUCTION

The operation of VTOL aircraft in forward, remote, or dispersed areas will require preparation of sites to prevent the exhaust effects of the aircraft from raising clouds of dust and debris. Flying debris and dust could damage the propulsion system by ingestion of foreign objects, damage the aircraft structure, obstruct the pilot's vision, and unnecessarily disclose the aircraft's position. Establishing sites in remote and front-line areas will require that the method of site preparation be economical, be capable of being accomplished rapidly without aid of heavy equipment, and be effective under a variety of soil and weather conditions.

The Air Force Aero Propulsion Laboratory has conducted in-house research and sponsored contractual effort to develop effective techniques and materials for preparing such sites. A unique test facility has been set up to conduct in-house research on materials for rapid preparation of such sites. A J-85 jet engine with afterburner was mounted so that it could be rotated to a vertical position in a test rig and when it was run its exhaust effects would simulate those of an actual VTOL aircraft during landing and take-off. Tests of various site-preparation materials were conducted with this facility. An actual full-scale test of site prepared with the most promising material was also conducted using an X-14 VTOL aircraft at Moffett Field, California. The results of these tests and an analysis of the results are presented in this report.

DESIGN CRITERIA

The first step in the research effort was to establish design and testing criteria for a VTOL site-hardening program. The various conditions imposed by operating the aircraft, including temperature, pressure, and velocity, were investigated. These conditions are described and illustrated as follows:

Figure 1 illustrates the disc loadings in pounds per square foot that are imposed by various types of VTOL aircraft designs. These loadings range from 5 psf for various types of helicopters to higher than 3000 psf for a jet VTOL aircraft with afterburner such as the German VJ-101 series. Figure 2 illustrates the resistance of various types of terrain to various disc loadings. Relating the values in Figure 1 to those in Figure 2 shows that any of the aircraft loadings will cause all of the natural soil surfaces to erode. Heavy grass sod withstands the greatest loadings, but its resistance lasts for only a short period of time (maximum of 10 seconds). The resistance of sod varies, too, and depends greatly on the quality of the sod as to root structure, soil base, and density. A comparison of Figures 1 and 2 illustrates clearly the need for site preparation where VTOL aircraft are to be operated.

Figures 3 and 4 show the temperature and velocity of the slipstream for various types of VTOL aircraft. These environmental conditions combined affect the resistance of various soil hardeners greatly and have to be considered as acting simultaneously. The combination of tremendous heat (3000°F for afterburner conditions) and high scrubbing velocities will readily decompose most soil hardeners.

Analysis of the above environmental conditions imposed by the various VTOL aircraft indicated that the jet aircraft with afterburner imposed the most stringent conditions to which the VTOL site would be exposed. These conditions, therefore, were chosen as the design criteria for the study. The parameters are listed as follows:

- a. Temperature Resistance: 3,000°F
- b. Blast Pressure Resistance: 2500 psf
- c. Site Preparation Time: Maximum of 4 hours
- d. Maximum Prepared Area: 2,000 sq ft
- e. Maximum Weight of Preparation Material: 80 lbs/cu ft
- f. Preparation Under Weather Extremes: 25°F to 105°F
- g. Soil Base: Clay, sand, sod, or gravel under various conditions of wet, cold, dry, or acid

From these requirements, the following VTOL site hardening goals were established:

- a. Site Material Cure Time: 15 minutes
- b. Pounds/Sq Ft Material on Site: 1/2 to 5 lb/sq ft
- c. Application Techniques: On ground or from aircraft
- d. Preparation and Cure: Under various weather extremes
- e. Cured Site Resistance: 3000°F and 2000 psf
- f. Cost of Material: \$0.25/lb, ± \$0.05
- g. Site Take-off Strength: 20 operational cycles
- h. Soil Stabilization Method: Penetrate or overlay
- i. Material Storage: Shelf life of 1 year minimum

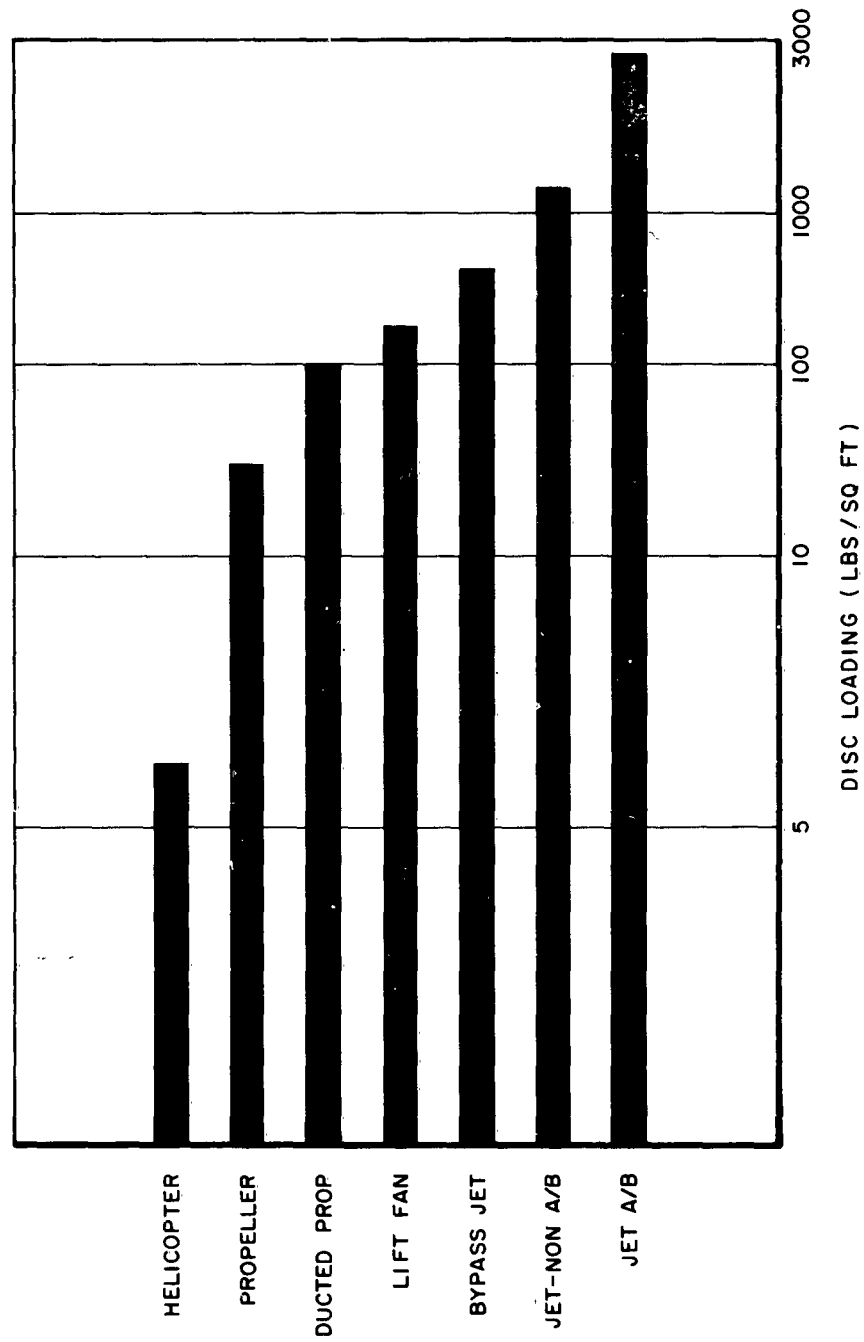


Figure 1. Ground Overpressure Environment

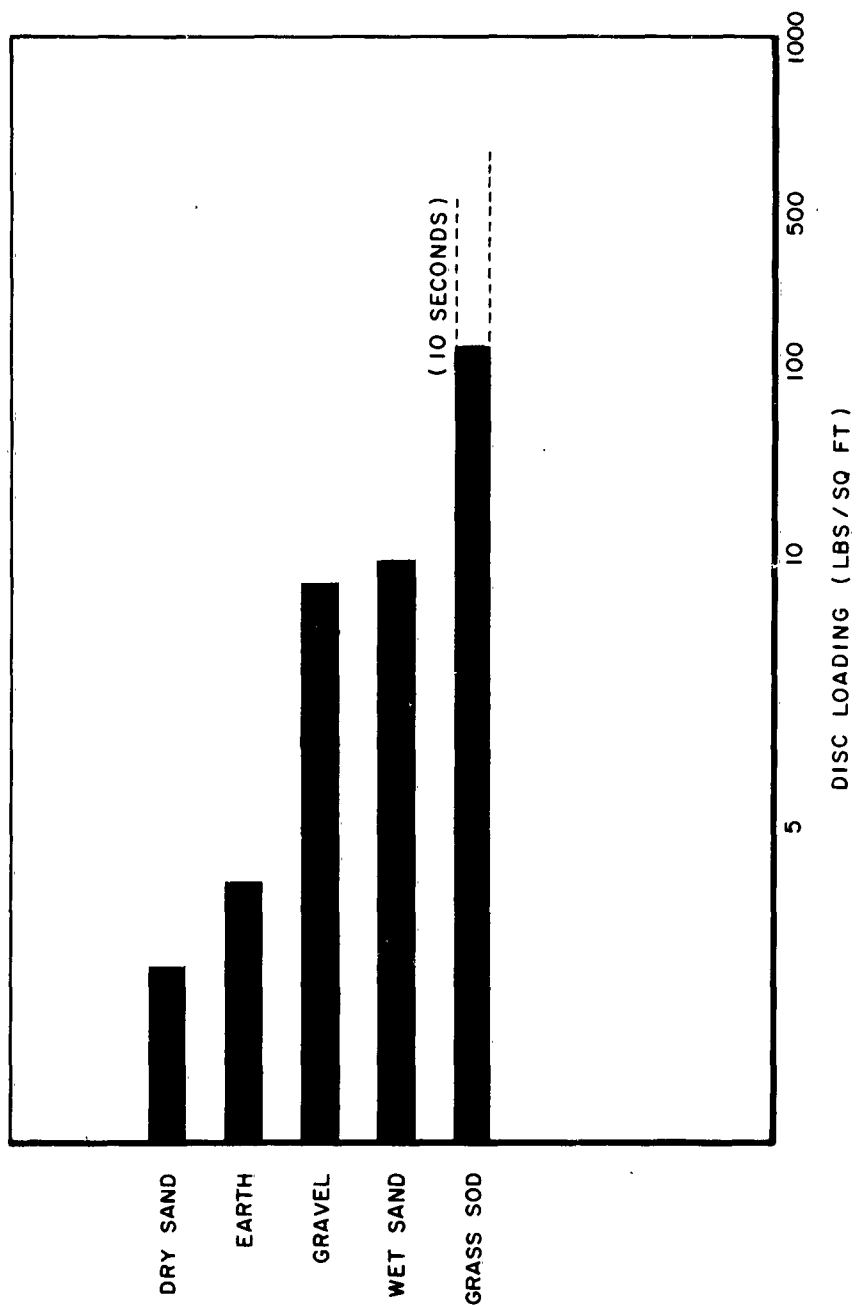


Figure 2. Terrain Resistance to Overpressure

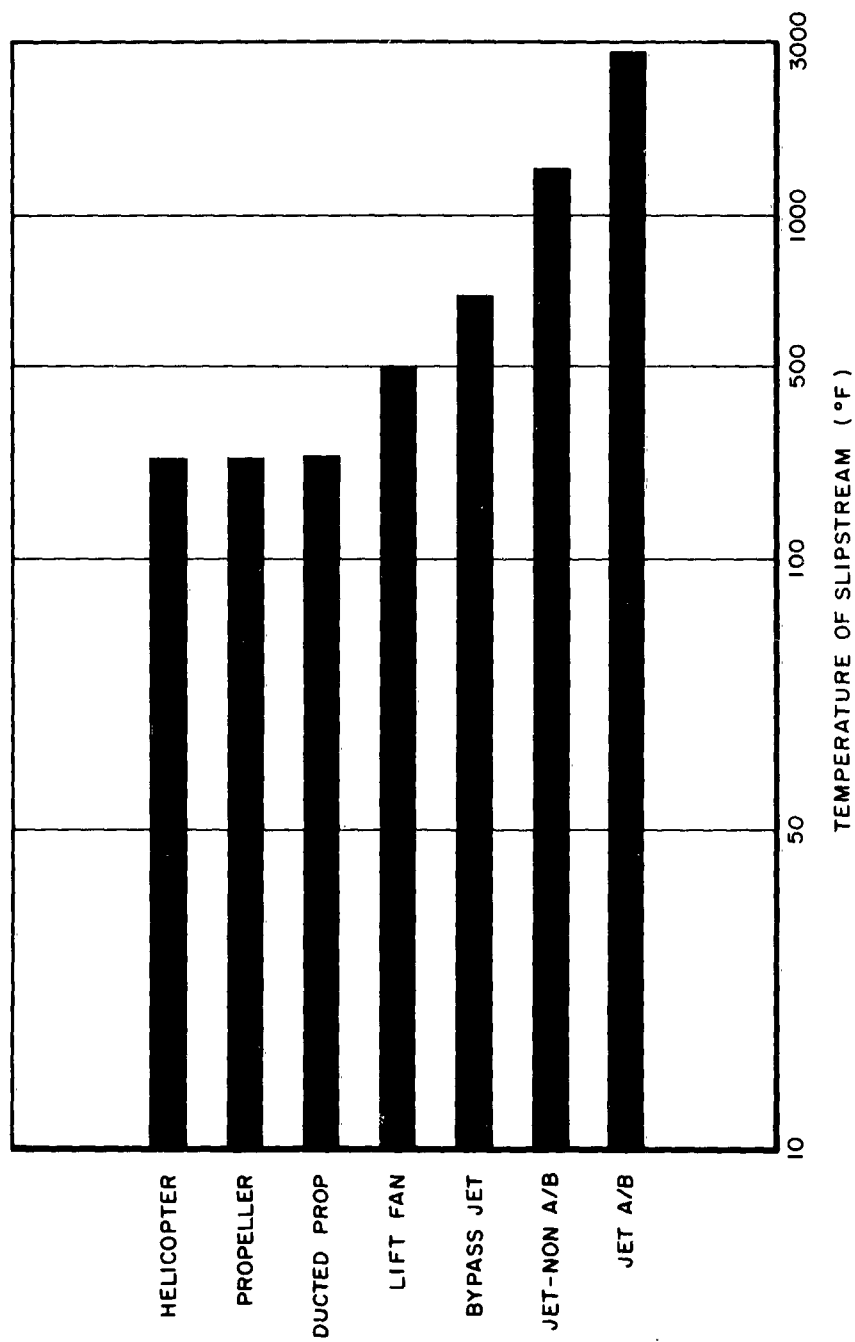


Figure 3. Slipstream Temperature Environment

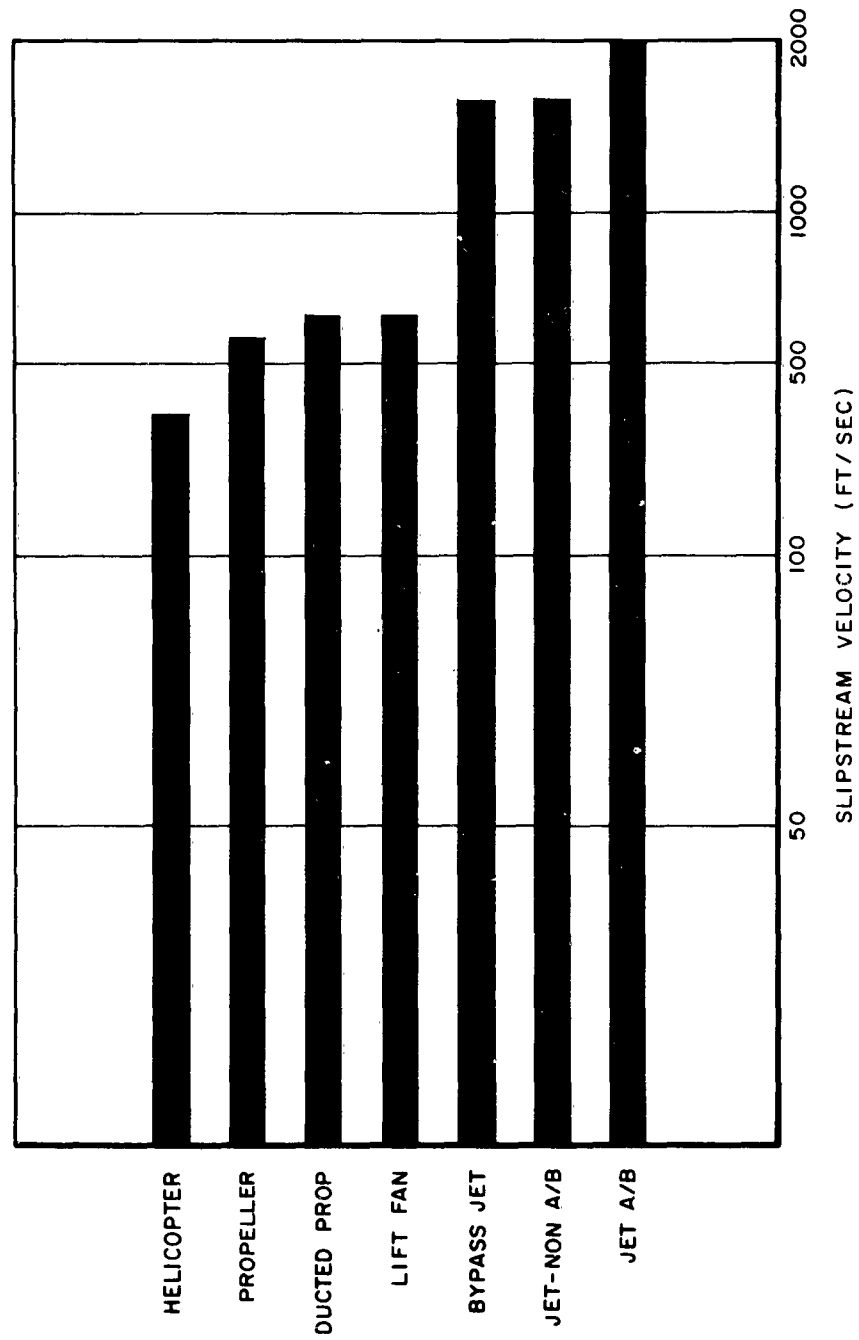


Figure 4. Slipstream Velocity

TEMPERATURE RESISTANCE

The impingement temperatures for various ratios of nozzle height/nozzle diameter (H/D) are shown in Figure 5. The temperature chosen as the goal for this study was 3000°F because a VTOL jet aircraft with afterburner would impose this temperature when in a vertical position with its exhaust nozzle three to four feet above the pad. This high temperature severely limits the type of material that can be utilized in preparing the site. At temperatures well below this level concrete chips and spaulds, asphalt melts and splashes, and wood burns and chars, and most organic resins melt or burn at temperatures between 600°F and 800°F. This information and results of research conducted by Industry on temperature resistance of materials in small-scale experiments at jet exhaust temperatures were used in the initial screening and selection of materials for these experiments on VTOL site hardening.

BLAST PRESSURE RESISTANCE

The blast pressures that a prepared site would have to resist would also be those imposed by the jet aircraft with afterburner, or 2500 psf. Tests conducted by NASA and several industrial concerns have shown that soil erosion is dependent on the dynamic pressures imposed by the outward flow of the air at the ground surface. This and other data, as shown in Figure 2, indicate that sand and loose dirt will start to erode at a dynamic pressure of 5 psf, gravel at 10 psf, and wet compacted sand at 15 psf. Well-rooted sod has withstood pressures of 1000 psf, but only for a short period of time. The J-85 jet engine without afterburner mounted vertically on a fork lift created a hole 8 inches deep, 6 feet long, and 5 feet wide on well-sodded ground when tested at Wright-Patterson Air Force Base, Ohio; the engine was run for 20 seconds at a nozzle height of 5 feet above the ground surface.

SITE PREPARATION TIME

The amount of time required to prepare a site is a function of the type of equipment and the number of personnel available. Large numbers of troops and special items of equipment will probably not be available at remote or front-line sites. If they are available, we assume that there would also be transportation available for bringing in landing platforms or mats. In front-line operations, these would not be desirable because of the logistics and personnel requirements that this technique imposes.

The most convenient technique for preparing a front-line site would be to spray a substance on the ground that would harden and form a surface that can resist the blast environment of the VTOL aircraft. This is the technique that is currently being investigated by the Air Force Aero Propulsion Laboratory for front-line operations. A time period of four hours from beginning to apply the material until the site is cured and ready for use was established as the maximum time permissible. For front-line operations, a time period of 15 minutes would be more desirable. The time required depends on the material to be used in preparing the site, the techniques used in applying it, and the size of the site to be prepared.

SITE APPLICATION TECHNIQUES

Three methods of preparing VTOL sites rapidly that are appropriate for remote and front-line operations were considered for investigation. These methods are discussed as follows:

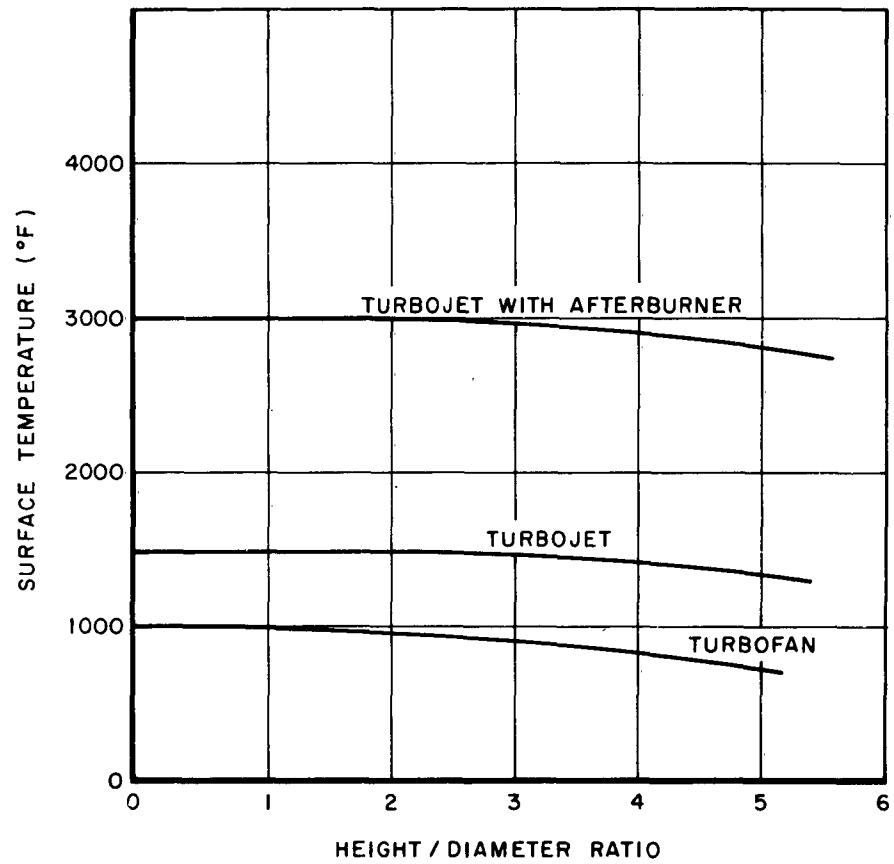


Figure 5. Surface Temperature Environment

a. Ground Application Technique. A jeep-type vehicle or tow vehicle would move over the site and the material would be sprayed from equipment mounted on the vehicle. Two or three men would be required to operate the vehicle and equipment.

b. Air Drop Technique. In this approach, the aircraft carries its own landing site material in a frangible container or flexible bag. As the aircraft flies over the site, it drops the container; the flow or splash from the container forms the landing pad. (A buddy-type aircraft could accomplish this airdrop as well as the VTOL aircraft itself.)

c. Air Spray Technique. The aircraft hovers over the area of the intended landing pad and sprays the material from special equipment installed on the plane, similar to the technique employed in spraying crops from an aircraft.

MAXIMUM AREA TO BE PREPARED

The principal advantage of the VTOL aircraft is that it requires little area for landing and take-off compared with that required by conventional aircraft. The maximum area required for the VTOL site was based on that required by the pilot for maneuvering and for the effects of the jet blast velocity and temperature to decay. Previous tests conducted by NASA have indicated that the decay of dynamic pressure behind a jet nozzle is dependent on the diameter of the jet. In these tests, a four-inch nozzle produced lower values of dynamic pressure for the same H/D ratio than a 16-inch ducted fan produced. These effects indicate that considering the relationship of H/D in the design of VTOL aircraft may lead to using several smaller jets rather than one large one to alleviate site impingement problems.

The temperature and velocity decay rate indicates that only a minimum area directly under the jet will need extensive protection from the most severe effects of the blast pressure and temperature. The surrounding areas will require a lighter protective covering to suppress soil erosion. A 50-foot-diameter pad (2000 square feet) may be sufficient to control erosion from some types of VTOL aircraft. Some researchers have established an arbitrary criterion of two wing diameters as the size landing pad required by a specific aircraft. The actual size of pad required will depend upon the size of the aircraft to be operated on it, the type of design, the size and number of engines, and the location of the engines. In addition to the size of pad that the aircraft requires, the pad must be large enough to enable the pilot to see the landing site so that he will not stray over the edges and encounter a critical debris problem.

Another consideration must be included in determining the size of the pad, and that is the landing pattern of the VTOL aircraft. If the aircraft can make a vertical descent from an altitude of 100 feet, no approach zone will be required. Vertical descent from this altitude necessitates that the pilot be in the "dead stick" zone for a long period of time. Most pilots prefer to approach from a 15 to 20 degree angle and descend vertically from an altitude of 50 feet or less. A ducted-fan or VTOL aircraft without afterburner will cause ground pressures exceeding 50 psf at a distance of 100 feet from the 50-foot-diameter pad, as shown in Figure 6, which pressure is sufficient to raise clouds of sand and gravel. The Boeing Company has estimated ground pressures imposed by different types of engines, as shown in the curves in Figures 7 and 8.

The size of the pad must be held to a minimum, since the larger the pad, the more material will be needed to prepare it. A material cover rate of 2 to 4 pounds per square foot may be needed for the central area exposed to the severe jet blast environment and 1

pound per square foot for the protective dust cover. For large-size sites, the weight of the material needed for preparing the site would be excessive and would cause front-line logistics problems. For each aircraft design, therefore, the minimum pad size must be calculated based on the various parameters discussed above.

SOIL AND WEATHER PARAMETERS

The VTOL aircraft will be capable of global operation. The site-hardening material, therefore, must be capable of providing satisfactory landing pads under extremes of weather and soil conditions. Soil conditions that might be encountered would include dry sands, clay, grassy sod, acid soils, and wet or cold soils. An all-inclusive resin material would be desirable, but practical formulations may have to be tailored to a specific type of soil or weather condition. This tailoring could be accomplished by varying the amount of catalyst or cross-linking agent or by adding special fillers.

MATERIALS TESTING

Tests accomplished by the Air Force Aero Propulsion Laboratory in which various sod and soil specimens were subjected to the blast environment of a jet J-85 engine without an afterburner that had been mounted on a fork lift had shown how this environment would erode unprepared surfaces. To further study the effects of the jet exhaust environment, a VTOL jet test facility was constructed. While this test facility was being constructed, several chemicals and resins were tested with an oxyacetylene torch facility. This series of tests indicated that the site-hardening material could overlay or penetrate the soil to provide effective blast resistance. Most hardening samples did not penetrate any of the soils except dry sand. Cold and wet soil conditions prolonged the cure times of various resins.

VTOL JET TEST FACILITY

The special test facility consisted of a J-85-5 jet engine with afterburner mounted to enable vertical rotation so as to simulate the actual VTOL blast environment. Samples of site-hardening materials were applied over different types of soil bases, and these samples were then mounted in a muffler frame. The muffler frame served to deflect the blast effects out of the test facility during the first phase testing, and enabled moving the sample to provide different H/D ratios. A photograph of the jet engine in vertical position blasting a sample is shown in Figure 9.

The first tests conducted with the VTOL test facility were 2-foot by 2-foot samples of soil-hardening material poured over various types of soil in a steel box. Pressure probes and thermocouples were installed in the sample, and the steel box was water-jacketed to cool the box and alleviate stresses caused by expansion. The samples were tested after letting them cure for times ranging from 1/2 hour to approximately 4 hours.

A test run consisted of a total time of 30 seconds, with 10 seconds at afterburner conditions. Ten such runs would be made on each sample unless the sample failed before the cycle was completed. Approximately 70 test cycles were conducted to evaluate the various soil-hardening materials. The evaluation included the application and curing times, strengths, and resistance to jet blast conditions.

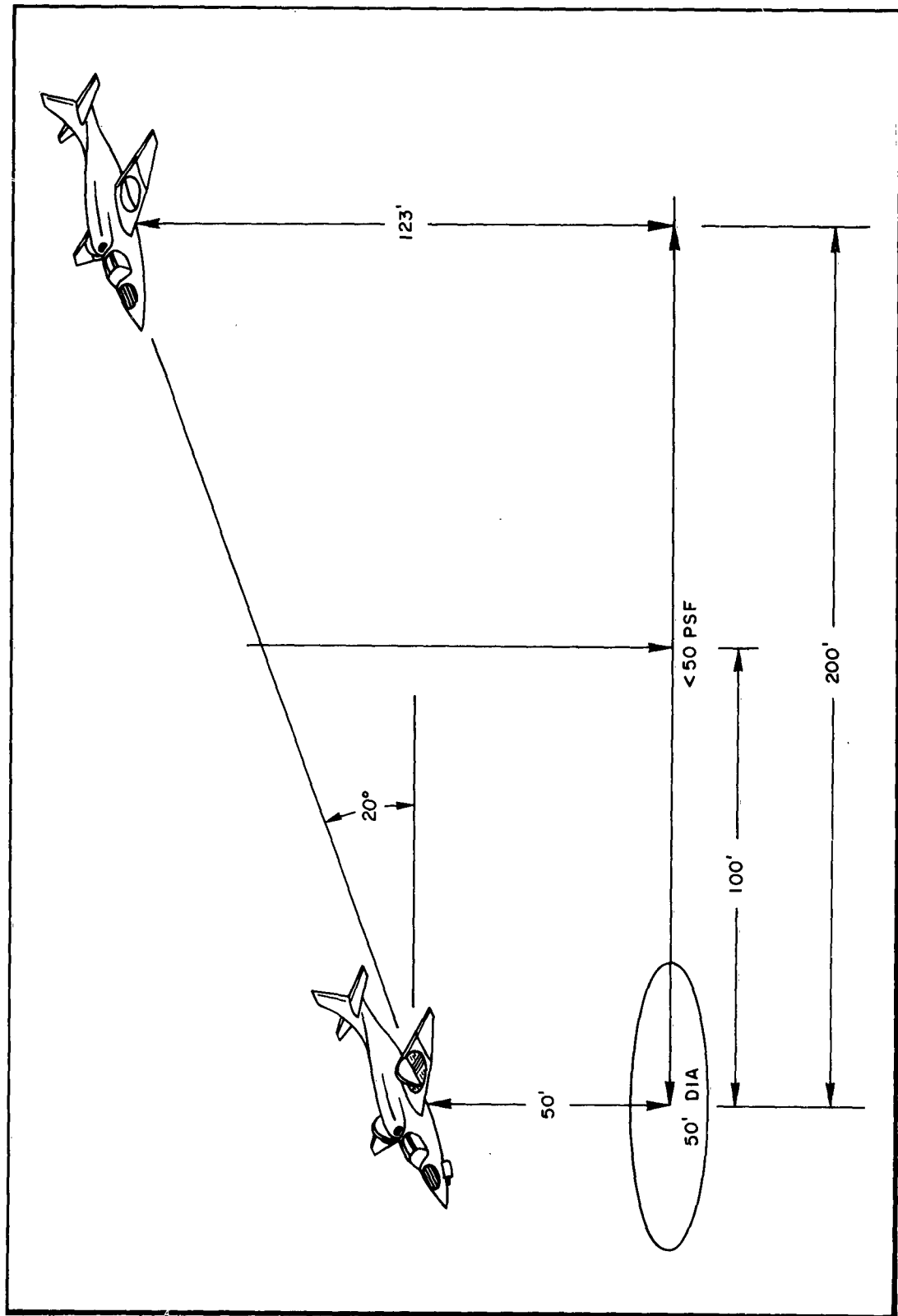


Figure 6. VTOL Aircraft Approach Zone Environment

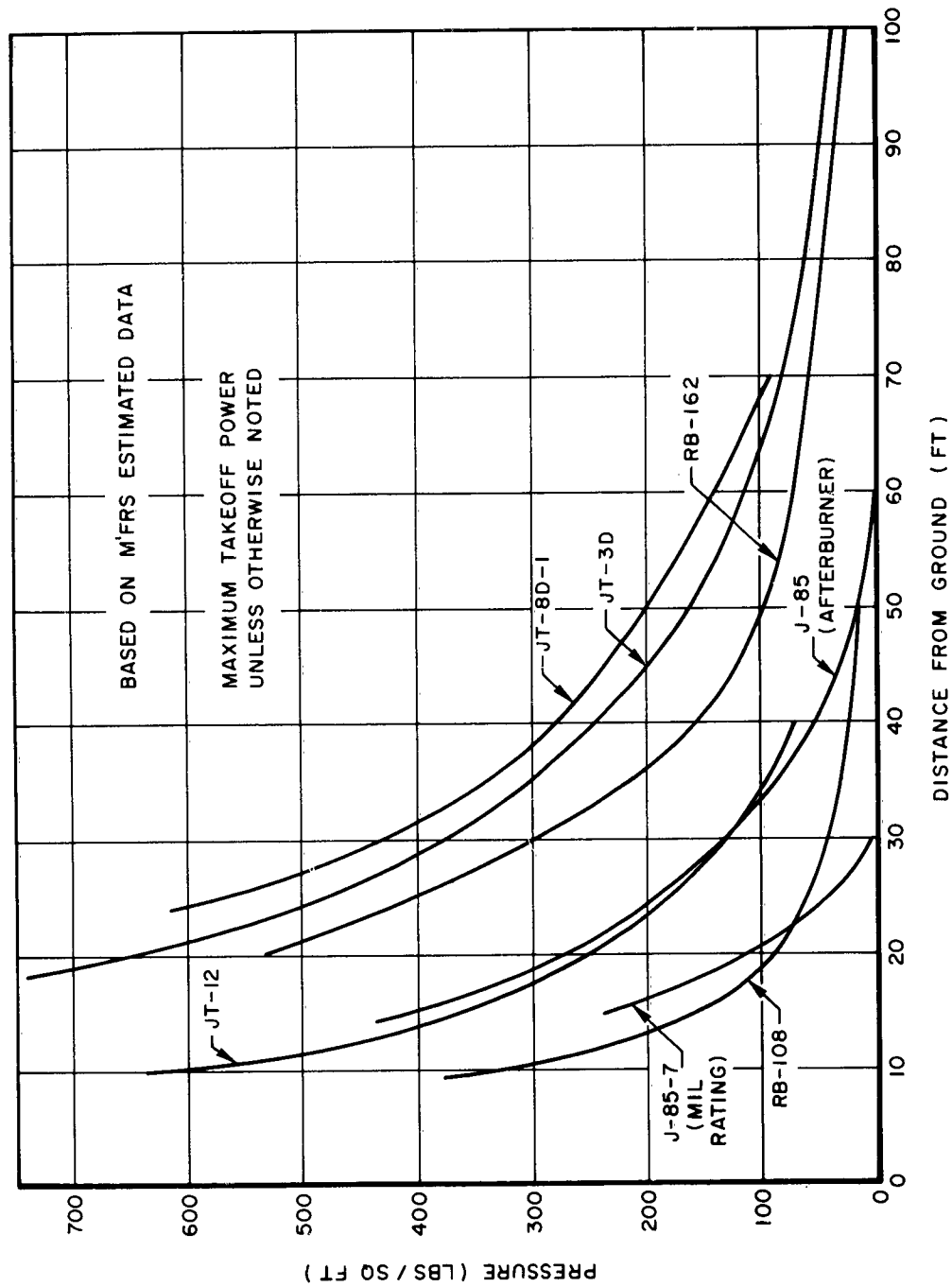


Figure 7. Degradation of Pressure From Engine Wake With Distance Above Ground

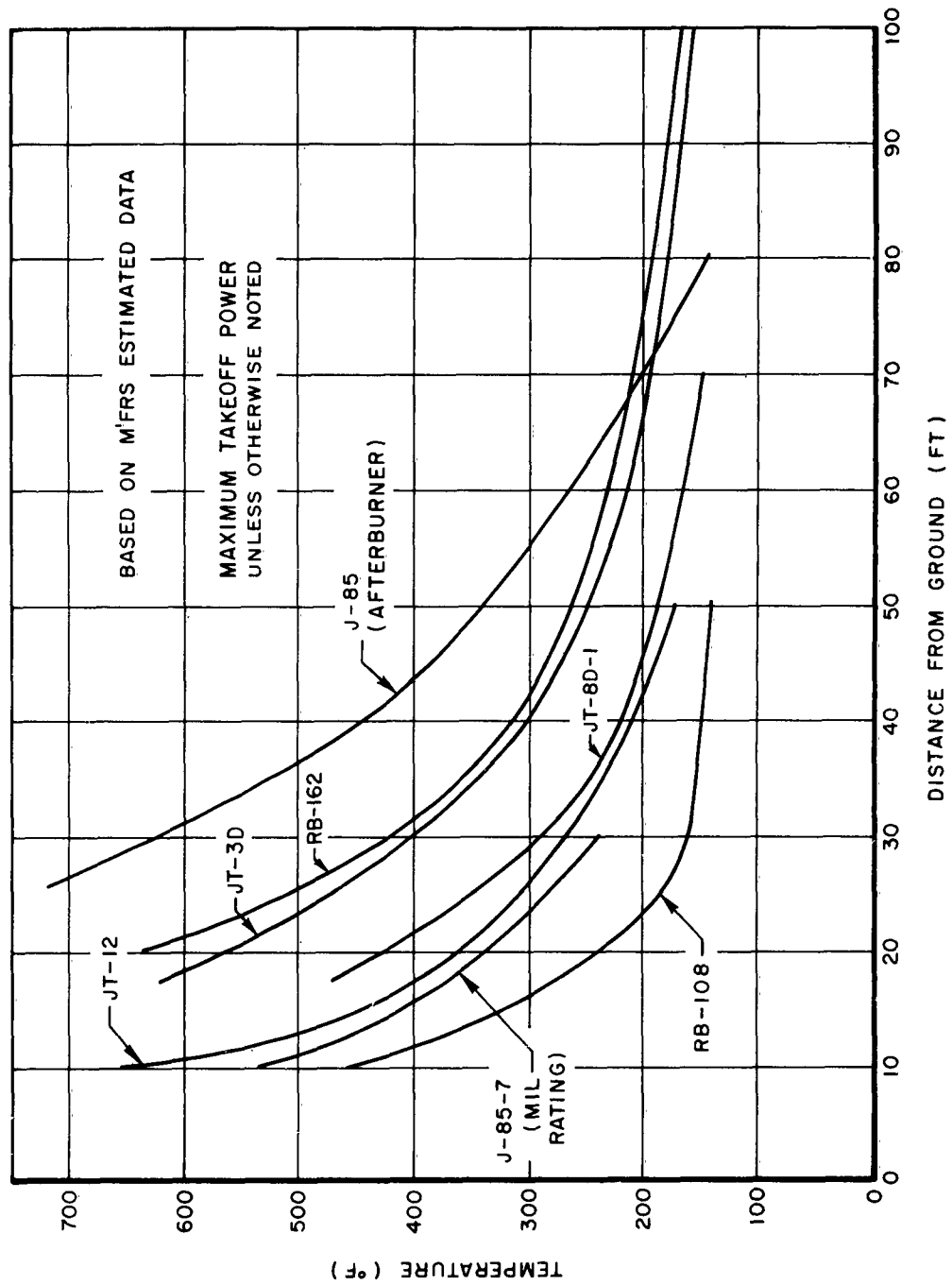


Figure 8. Degradation of Temperature From Engine Wake With Distance Above Ground

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The following procedure was used in operating the test facility:

- a. Start engine in horizontal position; check engine.
- b. Rotate engine to vertical position while operating in idle.
- c. Run engine to full military power (0 - 10 seconds).
- d. Operate afterburner (11 - 20 seconds).
- e. Cut engine to idle (21 - 25 seconds).
- f. Rotate engine to horizontal position (26 - 30 seconds).

SMALL-SIZE SAMPLE TESTS

Typical materials tested and results of tests are described as follows:

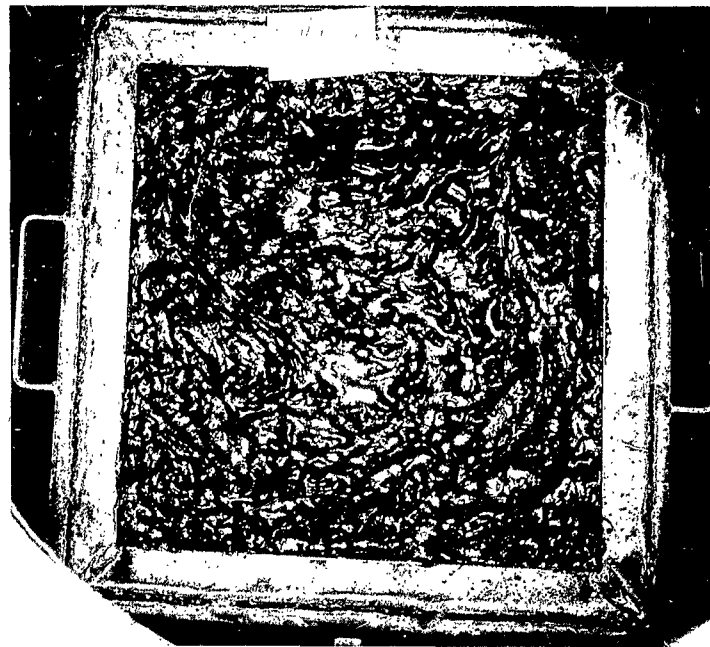
- a. Sample 17. Resorcinal Formaldehyde Resin, 1/2 inch thick; failure on 2nd run. Figure 10.
- b. Sample 18. Epoxy Resin and Chopped Glass Fiber, 1/2 inch thick; failure on 2nd run. Figure 11.
- c. Sample 20. Polyurethane Foam and Chopped Glass Fiber, 5 inches thick; failure on 1st run. Figure 12.
- d. Sample 31. Polylyte Polyester Prepolymer Resin, 1/2 inch thick; failure on 1st run. Figure 13.
- e. Sample 32. Runway Concrete, 4200-Pound, 1/2 inch thick; failure on first run (50% of sample eroded). Figure 14.
- f. Sample 39. Sodium Silicate, Zirconium Cement and Glass Fibers, 1/2 inch thick; failure on 1st run. Figure 15.
- g. Sample 44. Epoxy Resin and Glass Fibers, 1/2 inch thick; tested only at full military power for 100 seconds. Figure 16.
- h. Sample 51. Urethane Resin Over Sand, 1 inch thick; failure on first cycle. Figure 17.
- i. Sample 61. Filled Polyester Resin and Glass Fiber Mat, 1/2 inch thick; failure on 3rd run. Figure 18.
- j. Sample 63. Ceramic Cement and Glass Fiber, 1/2 inch thick; failure on 1st run. Figure 19.

The test results of the various site-hardening materials tested with the vertical J-85 jet test facility are summarized as follows:

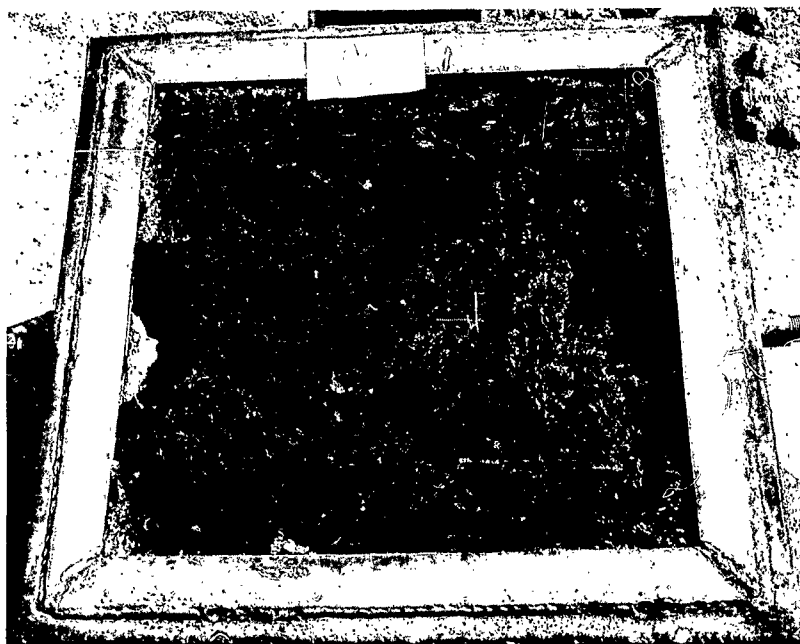
- a. Epoxy Resins. A one-half-inch thickness is good for 1.5 test runs, and a one-inch thickness is good for 3.0 test runs. Addition of fiberglass strands approximately doubles the life of the pad under afterburner conditions. Epoxy resins are difficult to work in cold weather, strength is affected by amount and type of catalyst, and an irritating gas is given off during curing cycles. Cure times as low as 18 minutes were obtained. Epoxy resin became soft and was ablated or burned away during tests.
- b. Urethane Resins. Surface is poor over impervious soils, somewhat better over sand. Resin turns to fluid at higher temperatures and loses binder strength. Cure times



Figure 9. VTOL Jet Blast Test Facility, Vertical Position

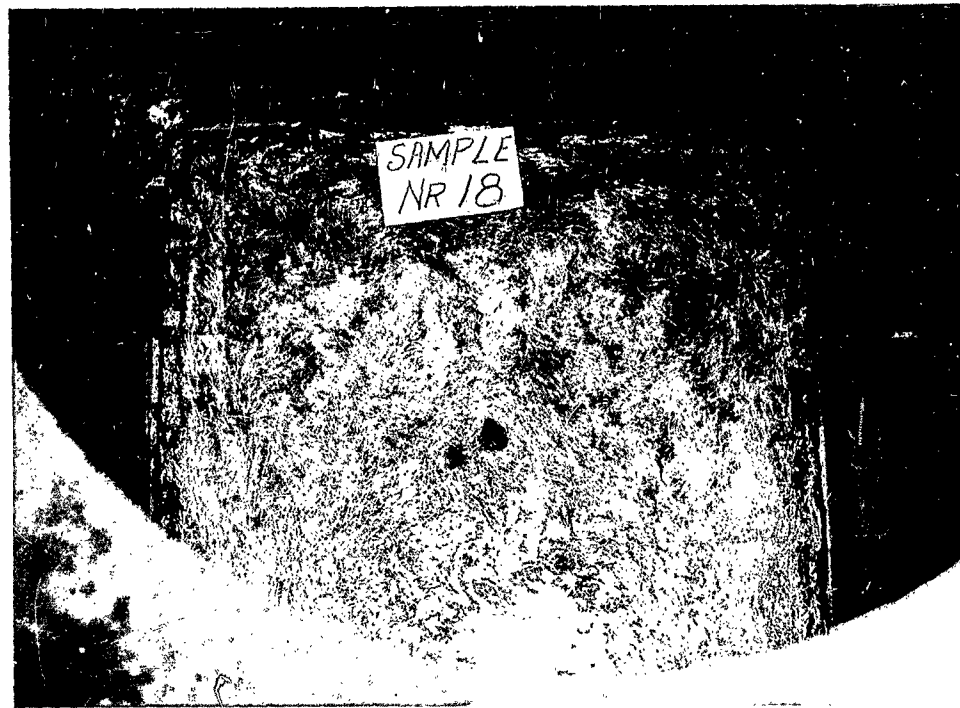


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Figure 10. Resorcinal Formaldehyde Resin Sample, Before and After Test



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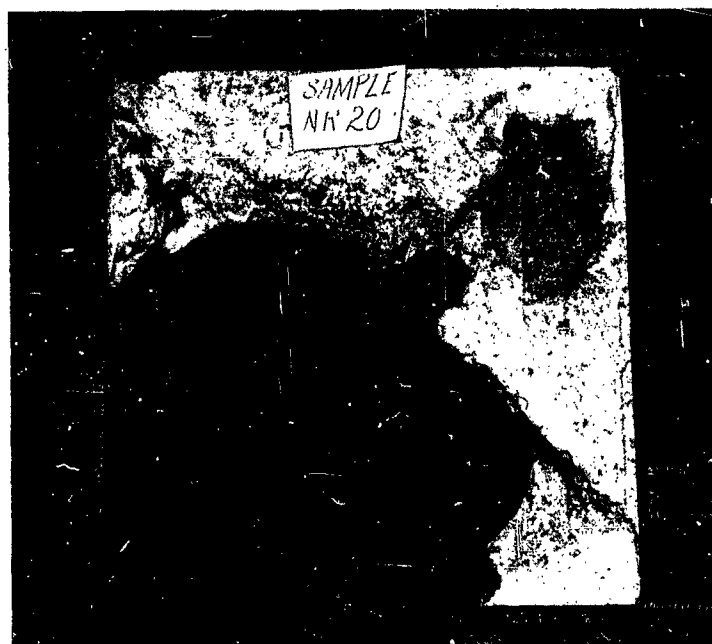


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Figure 11. Epoxy Resin and Chopped Fiber Glass, Before and After Test



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Figure 12. Polyurethane Foam and Chopped Fiber Glass, Before and After Test

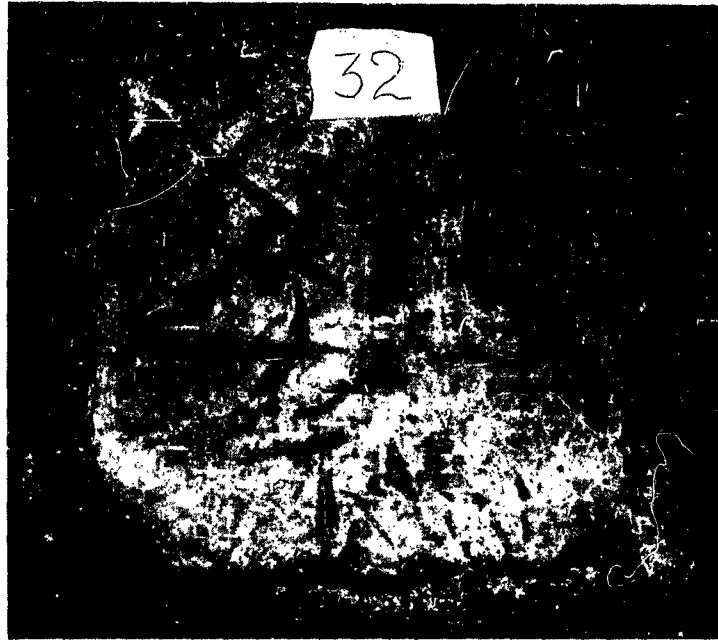


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Figure 13. Polylite Polyester Prepolymer Resin, Before and After Test

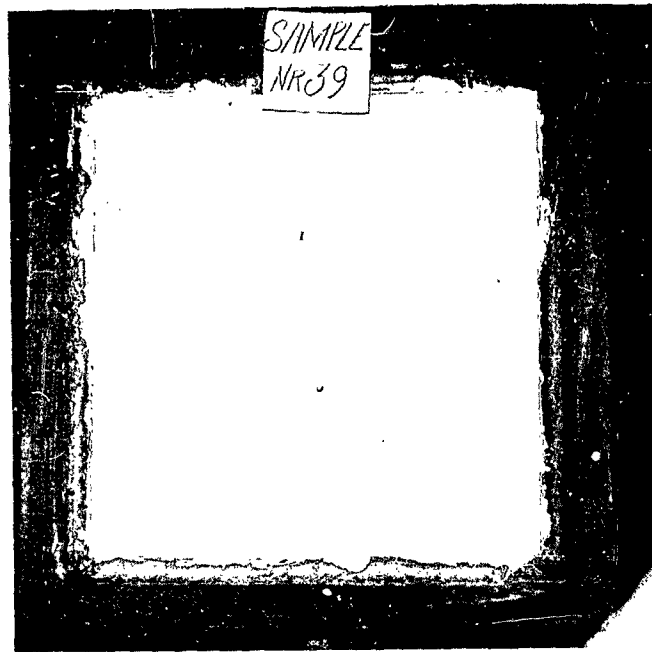


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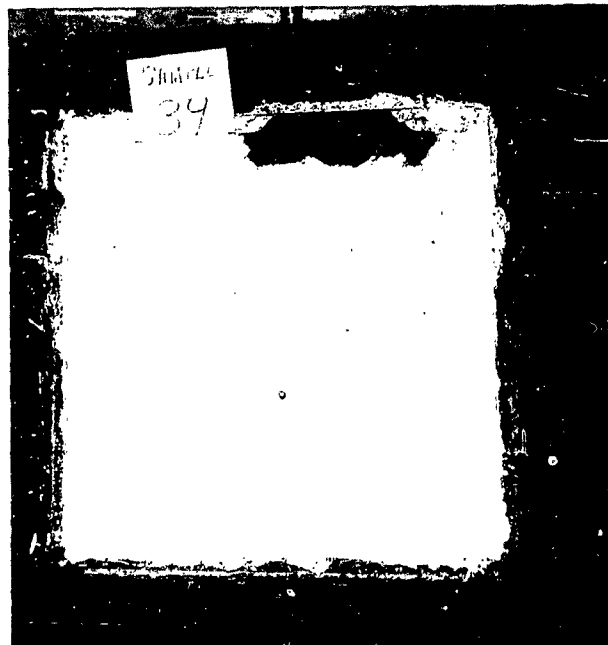


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Figure 14. Runway Concrete, 4200-Pound, Before and After Test

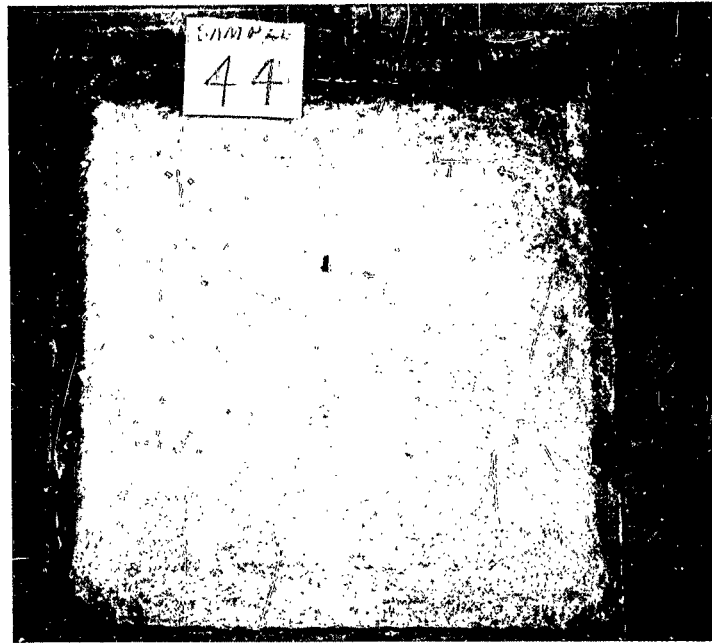


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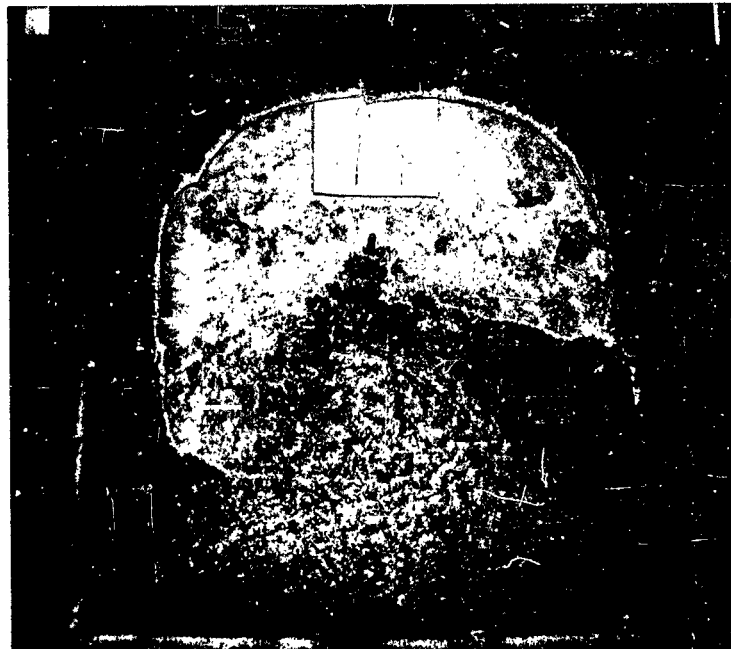


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Figure 15. Sodium Silicate - Zirconium Cement and Fiber Glass, Before and After Test



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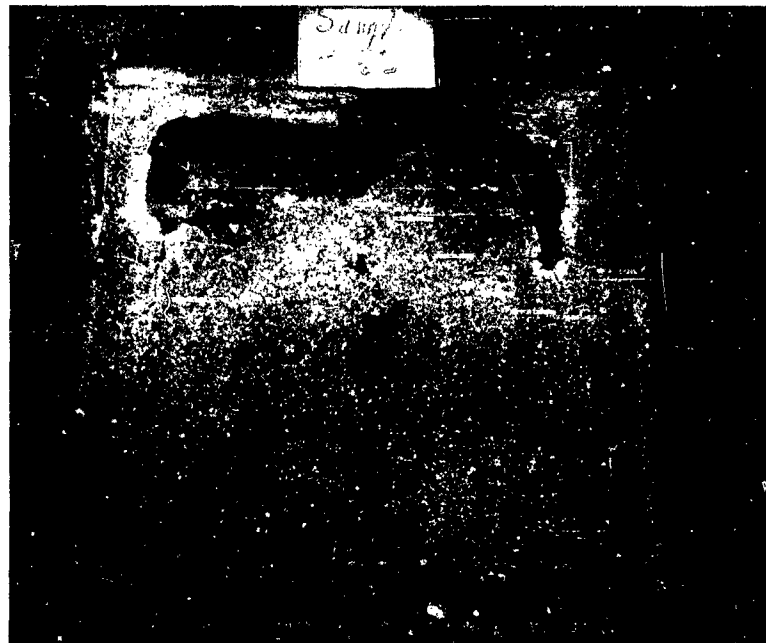


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Figure 16. Epoxy Resin and Fiber Glass, Before and After Test at Full Military Power for 100 Seconds

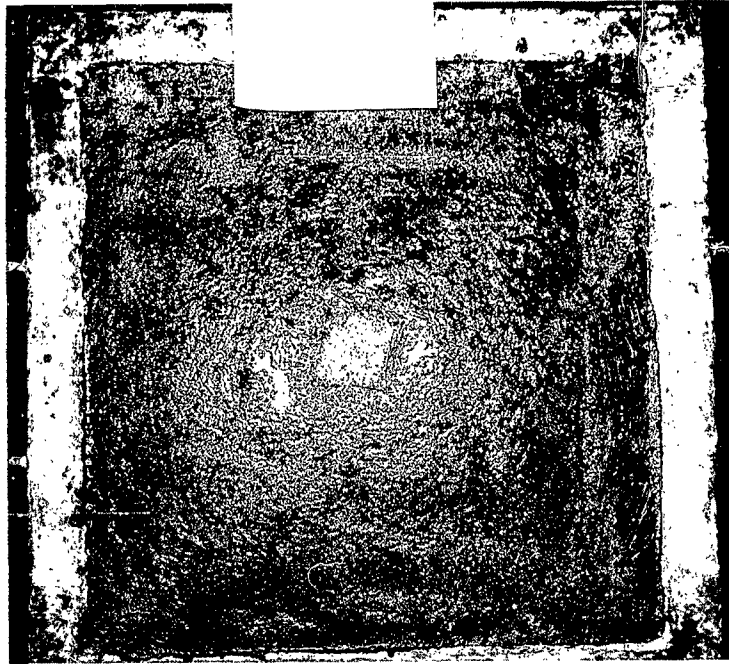


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Figure 17. Urethane Resin Over Sand, Before and After Test

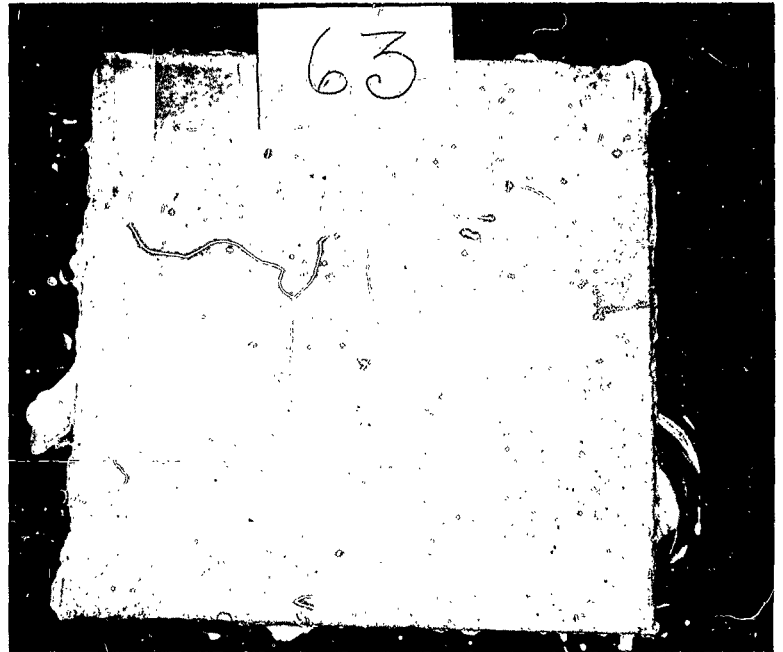


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Figure 18. Filled Polyester Resin and Fiber Glass Mat, Before and After Test



BEFORE



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Figure 19. Ceramic Cement and Fiber Glass, Before and After Te

as low as 15 minutes were obtained. Material is easy to work but cure is affected by water content of soil.

- c. Urethane Foam. Two-component resin formulations require accurate mixing. Lower density foam is easily eroded by afterburner blast, but higher density foam is somewhat better.
- d. Resorcinal Formaldehyde Resin. Cure is affected by the pH of the soil and by water. The material chars easily throughout the total mass, and an irritating odor remains after the material is cured. The material requires an accurate mix.
- e. Ceramic Cement (Sauereisen and Glassrock Cement). Various chemical binders affect strength; some show good strength. The material requires several hours to cure. Some cements went the full cycle of tests without failure. The surface requires troweling because of heavy density.
- f. Gelatin. This material readily melts under heat conditions.
- g. Regular Runway Concrete. The material requires troweling for placement and many days to cure. Concrete chips and spalls under extreme heat conditions.
- h. Refractory Concrete. Cure time is good (less than 1 hour) but cure was affected by water content of soil. Material is difficult to work due to heavy density. Several samples went full test program.
- i. Polyester Resins. Cure time is good. Strength is not affected by amount of catalyst. Material can be sprayed or poured and will cure over various types of soil in wet or cold conditions. Various fillers affect strength and performance under afterburner conditions; fiber glass enhances strength. Several samples went full test program.

LARGER SCALE TESTS

After the results of the small-size sample tests were analyzed, the most promising material was to be selected and fabricated into a 9-foot-diameter pad, and this pad would then be tested in the VTOL test facility. The results of these sample tests, as well as other tests conducted by Ling-Temco-Vought under Contract AF33(615)-1092, indicated that a chlorinated polyester resin with special temperature-resistant additives was the best all-around material for rapid VTOL site preparation. In addition, the polyester resin material is less expensive than most resins, much experience has been gained with it in industry, and it is easier to work than other resins. With the addition of a catalyst (MEK, Methyl Ethyl Ketone Peroxide - 60%) at a ratio of 1.5%, the resin has been cured over acid and basic soils and in temperatures ranging from 25°F to +105°F. Several samples with fiber-glass strands as reinforcement and granular boric acid and antimony trioxide as temperature-resistant additives withstood the entire series of blast tests in the small-scale test program.

The first large-size pad of polyester resin (9 feet in diameter) was fabricated in March 1964. The resin was sprayed over the soil with a rotary pump, hose, and spray nozzle. Fiber-glass strands were blown from a spool with compressed air through a flexible hose and into the pad. (This glass gun was on loan from the Archilithics Company, Dallas, Texas.) The resin and fiber glass were sprayed on the pad until the layer was 1/2 inch

thick. The material formula consisted of the following:

Polyester resin	56%
Granular boric acid (H_3BO_3)	32%
Antimony trioxide (Sb_2O_3)	5.5%
Glass fiber	5.0%
MEK catalyst	1.5%

Theoretically, the boric acid (H_3BO_3) forms a gas boundary layer that insulates the pad against the heat and gas velocity; it forms a glassy layer that acts as an ablator and hard char to resist scrubbing. The char also radiates high heat input back into the atmosphere. The antimony trioxide (Sb_2O_3) acts as a flame retardant, and the glass fiber is a load-carrying filler. This formulation cured in 15 minutes after the last layer was applied. A completed 9-foot-diameter, 1/2-inch-thick pad is shown in Figure 20; Figure 21 shows the pad during test and Figure 22 shows it after being exposed to 10 test cycles in the VTOL test facility. The total time of each test cycle was 20 seconds and consisted of the following:

0 to 10 seconds: Engine idle to full military power	10 seconds
11 to 16 seconds Afterburner conditions	6 seconds
17 to 20 seconds Shutdown to idle	4 seconds
Total	20 seconds

Total test times varied ± 2 seconds due to reaction time of operators and rotating mechanism. The first test was completed 3.5 hours after the pad was fabricated. The following test cycles were run:

Test Runs	Height Above Engine (inches)	Total A/B Time (seconds)	H/D	Total Test Time (seconds)
No. 1 to 4	64	21	4	77
No. 5 to 8	53	24	3	77
No. 9	36	6	2	25

At the end of the test cycle, a 1/32-inch layer of char covered the top of the pad over approximately 75% of the area, as shown in Figure 22. No burned-through areas were noted, however, and the material did not appear to be severely damaged by this testing. To further determine the condition of the material, the pad was removed intact from the test facility to a concrete ramp where a fork lift truck made several passes over it. This caused no cracking of the material in the pad.

Since the amount of material to be used in fabricating the pad is an important criterion, another 9-foot-diameter pad only 1/4-inch thick of the same resin and fiber-glass material was constructed on a compacted clay base.

This pad has somewhat less than 2.5 pounds per square foot of the material applied to the surface. The following tests were conducted on this pad after a cure time of 4 hours:

Test Runs	Height Above Engine (inches)	Total A/B Time (seconds)	H/D	Total Test Time (seconds)
No. 1	65	Full military power only	3	77
No. 2 and 3	65	12 seconds	3	60
No. 4 to 10	53	42 seconds	2	210

At the end of the tenth run, several small holes appeared in this pad. The ten test cycles, however, represent an operational time of 20 VTOL aircraft take-offs and landings because of the severity of the test conditions.

FULL-SCALE TESTS

To prove the capability of the special polyester material in fabricating satisfactory sites for VTOL aircraft on a full-scale basis, a test program using the X-14 jet VTOL aircraft was arranged in co-operation with NASA Ames, Moffett Field, California. This program was designed to test both the material and the fabrication techniques. NASA Ames was to furnish the X-14 aircraft and pilot, and the Air Force Aero Propulsion Laboratory would prepare the sites from which to operate the aircraft. The X-14 VTOL aircraft is powered by two vectored thrust J-35-5 jet engines that are mounted horizontally in the aircraft fuselage. The aircraft weighs approximately 3500 pounds and has a tire pressure of 40 psi.

To conduct these tests, equipment and materials were procured and transported to Moffett Field. Special equipment for fabricating the site included:

- a. Two special rotary pumps designed to pump resin.
- b. A gasoline drive system for the pump.
- c. A portable air compressor.
- d. An alternator.
- e. A fiber-glass spray gun (provided by Archilithics Company, Dallas, Texas).
- f. Hoses and special spray nozzles.

The pump was to suck the material from the container and force it through a 30-foot hose that would be used to apply the material to the site. The resin material was packaged in 10-gallon containers, and the catalyst was to be added to the material just before it was to be sprayed. It was found, however, that the granular boric acid in the material had settled to the bottom of the containers during shipment and storage. These grains had to be spaded loose and the material remixed before it could be sprayed. A blade-type agitator operated by the motor of a 5/8-inch hand drill was used for mixing the material. Research is being conducted to eliminate this settling problem.



Figure 20. Completed 9-Foot-Diameter Pad



Figure 21. Pad During Test



Figure 22. Pad After Being Exposed to 10 Test Cycles

The technique for fabricating the site consisted of overlaying the site area with fiber glass blown from the fiber-glass gun and spraying the resin material over the fiber glass. This process was to be repeated several times until a thickness of between $3/8$ and $5/8$ inch was built up on a pad 25 feet in diameter. This thickness is equivalent to a resin density of between 4 and 5 pounds per square foot.

The VTOL landing pad was fabricated on the morning of 23 June 1964. The soil base was a fine silty dirt with numerous 2-inch rocks. Dust was raised from this dirt by a very light wind. An area 25 feet in diameter was laid out near a concrete runway, and the resin material was applied as shown in Figure 23. When the X-14 pilot and the project engineer inspected the completed pad, however, they felt that the 25-foot-diameter pad did not provide sufficient area to dissipate the downblast of the X-14 aircraft from an altitude of 30 feet. Accordingly, a 7-foot lightweight dust cover was applied at a resin material density of 1 pound per square foot around the periphery of the 25-foot pad. This provided a site with a total diameter of 39 feet.

Flight tests were scheduled for early in the afternoon of the same day. After lift off, the pilot hovered at an altitude of about 12 feet above the pad. This hovering raised considerable dust and debris from outside the prepared area, which prevented the pilot from landing the airplane on the pad. Consequently, the tests were halted and an additional 10-foot lightweight dust cover was applied to the area surrounding the pad. This extended the site diameter to 59 feet. Since the pad had been located near the concrete runway, however, the shape of the 59-foot-diameter pad was a $3/4$ circle instead of round (as shown in Figure 26). Fabricating the pad had consumed a total of 3300 pounds of resin material and had required approximately two and one-half hours to apply the material. If the entire pad had been constructed at one time, however, the time requirement would probably have been less.

At that time, two visual markers were placed at a 90-degree angle to the center of the pad and far enough away from the center so that the pilot could sight them when landing the aircraft. The pilot used these markers to line up the aircraft for center-point landings and to be sure that the aircraft did not drift too close to the critical edge areas.

Flight tests were resumed the next morning with the X-14 aircraft being operated from the 59-foot pad. Performance was completely successful and included two take-offs, two landings, one 60-second run at 90% full military power, two roll-offs, and several low-altitude hovers. Finally, to determine the critical edge conditions, the airplane hovered at various altitudes over the edges of the pad to determine the altitude at which the lightweight cover would begin to deteriorate. When the aircraft hovered at an altitude of approximately 30 feet, the dust cover began to erode. Figure 24 shows the X-14 aircraft landed on the pad.

That portion of the pad directly impinged by the vectored blast of the X-14 aircraft was covered by a thin char, as shown in Figure 25. This char did not affect the strength of the pad; even 2-inch rocks on the surface of the soil base that had protruded and formed part of the pad were still held firmly in place. The depth of the char and its effect on the material correlated closely with results obtained in tests conducted in the VTOL test facility at Wright-Patterson Air Force Base.

Another test was planned for the next day in which another landing pad would be fabricated over grassy sod. After the fabrication material was mixed, but before it had been applied, the X-14 aircraft was crashed in a checkout flight not connected with this program.

This crash of the aircraft cancelled further VTOL site testing. Instead of preparing a new pad, therefore, the resin mixture was applied to the pad used for the previous tests so that the effects of weather on the material could be determined and to provide a site from which the X-14 aircraft could operate when it was repaired. The area damaged by the previous tests indicated that an approach zone should be provided. Consequently, the site was modified as shown in Figure 26.

From these full-scale site-fabrication experiments, we have concluded that:

- a. Rapid fabrication of VTOL operational sites in remote areas is feasible, although further research is needed.
- b. Operational sites must be large enough to dissipate blast velocity at the site edges or approach zones.
- c. The pad must be marked so that the pilot can determine where the critical edge areas or approach zones are.
- d. Each VTOL aircraft, due to its design, will impose different requirements for pad dimensions and thickness.

SITE APPLICATION TECHNIQUES

Three methods of rapidly preparing a pad in a remote area are being investigated for fabrication of forward VTOL operational sites. These are: (a) ground fabrication methods by a few men using a spray apparatus mounted on a dolly cart or jeep-type vehicle, (b) air drop from a VTOL aircraft, and (c) air spray from a VTOL-type aircraft.

GROUND FABRICATION METHOD

For the ground fabrication method, a cart or jeep-type vehicle is driven over the area, and the material is sprayed over the site from pumps mounted on the vehicle. Only a few men are required to quickly fabricate a large site. The jeeps and material could be air-lifted to a remote site by a CH3C helicopter (or other VTOL aircraft), which can carry two jeeps or combination of jeep and material. This technique was simulated in fabricating the pad for the tests at Moffett Field, since all of the equipment was mounted on a dolly cart for operation at the remote site.

The resin material in the future will be pumped from 55-gallon drums instead of the 10-gallon containers used in these tests. One problem to be resolved is how to inject the right proportion of catalyst into the drum and get adequate resin-catalyst mixing. Several injection systems are being investigated.

Currently, jeeps, pumps, T-bar, and catalyst injection equipment for this system are being investigated. This equipment is scheduled to be mounted on a jeep vehicle, and a test program is being integrated with a helicopter test for remote site operations.

AIR DROP TECHNIQUE

The air drop technique is being analyzed to provide either the VTOL aircraft or a buddy-type aircraft with the capability of manufacturing its own landing site in a remote or front-line area. Either frangible containers or flexible bags will be used to contain the



Figure 23. Fabricating the VTOL Site at Moffett Field

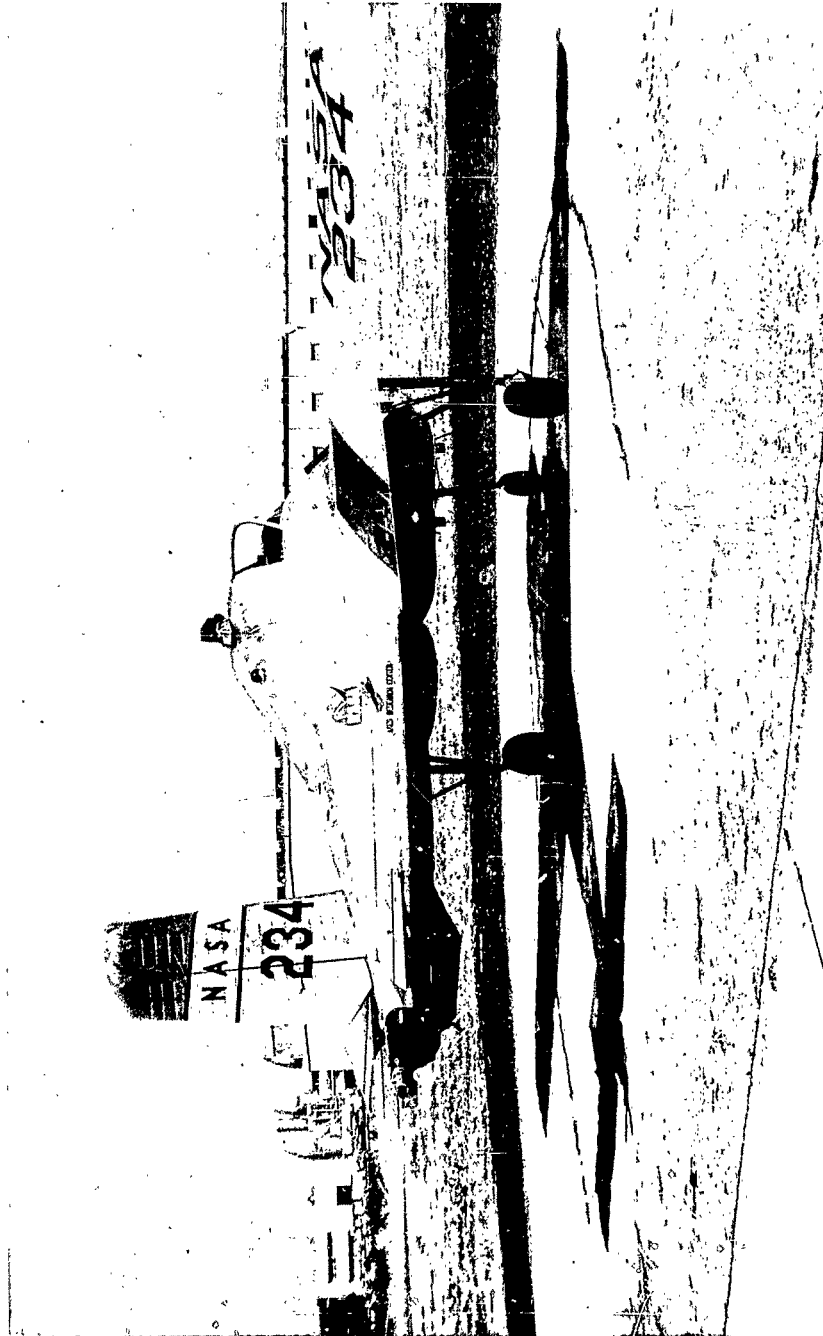


Figure 24. X-14 Aircraft on Fabricated Landing Pad



Figure 25. Landing Pad Showing Char From VTOL Aircraft Operation

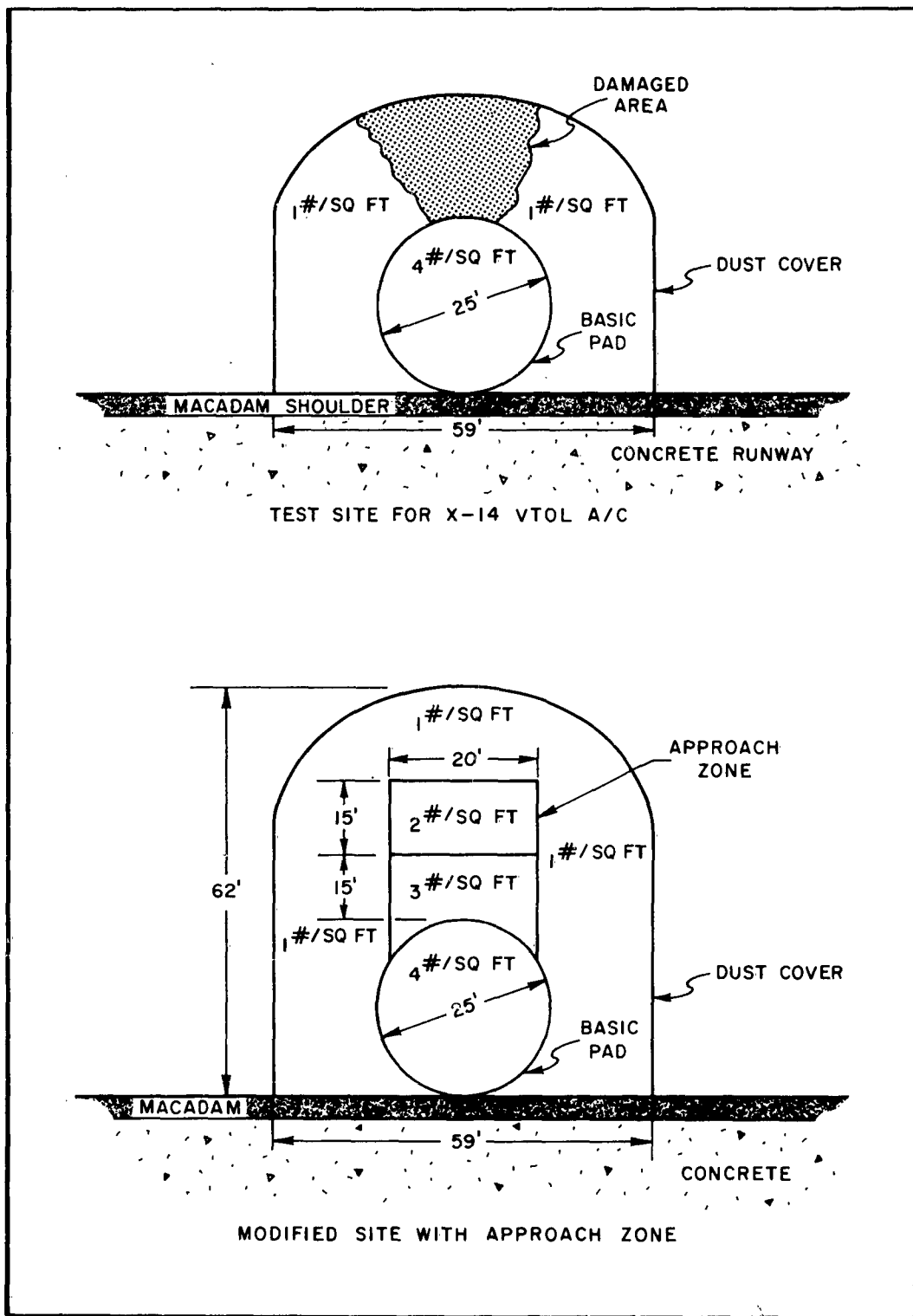


Figure 26. Moffett Field Test Sites

material, and these containers will be permitted to freefall from the aircraft. The splash or flow pattern of the material will manufacture the site. Figure 27 shows the flow pattern from a flexible plastic container used in these drop tests for manufacturing VTOL landing pads.

At present, the flexible-bag approach appears to have promise. The frangible containers give predictable results, but small pieces of the containers remaining near the site pose a potential ingestion problem to the VTOL aircraft. The flexible bag approach has been tested with water, viscous jell, and actual polyester resin. Twelve-foot-diameter bags dropped from a height of 28 feet have provided good fabricated sites. Future tests being scheduled include large-scale 20-foot-diameter pads to be dropped from a drop test facility, and a large-scale plastic container to be dropped from a helicopter. These tests will establish the feasibility of using this technique in fabricating remote sites for VTOL aircraft.

AIR SPRAY TECHNIQUE

The air spray technique will also allow the VTOL aircraft to fabricate its own site. This concept would utilize a spray system similar to that used for crop spraying. The aircraft would hover over the intended site and spray the soil-hardening material on the ground. Problems that will be encountered with this technique are the effects of the down-wash of the VTOL aircraft on the sprayed material, and obtaining a uniform thickness of the material on the prepared site. These problem areas are scheduled to be investigated in-house and contractually in 1965.



Figure 27. Pad Formed by Dropping Flexible Plastic Container

CONCLUSIONS

From the research conducted thus far on rapid site preparation for VTOL aircraft, we have concluded that:

1. There is a definite need for rapid site preparation when operating VTOL aircraft in remote areas.
2. The vertical J-85 jet engine test facility is a useful tool in evaluating the exhaust effects of VTOL aircraft on soil hardeners.
3. Some materials have been formulated that will withstand the afterburner effects of the J-85 jet engine. These materials are still being evaluated and more research is needed to alleviate filler settling problems and to design a simple catalyst injection system.
4. Fabricating large-scale VTOL pads from specially formulated polyester material is feasible, although the equipment for applying the material needs modification to be efficient and must be designed for rapid operation for use in remote areas.
5. Site size and fabrication materials will depend on pilot visibility, aircraft design, and soil conditions for the specific area. Pad edges and approach zones are critical design factors in fabrication of remote sites.
6. Only a smaller basic pad need be fabricated to withstand the direct blast of the VTOL aircraft engines. The remainder of the pad can be light weight, as it serves only as a dust palliative. For the basic pad, a density of 2.5 pounds per square foot (1/4 inch thick) of the material can resist direct VTOL afterburner blast, but 4 to 5 pounds per square foot (1/2 inch thick) is more desirable in the field due to uneven terrain or adverse soil conditions.
7. Further research into materials and application techniques is required.

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